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WEARING QUALITIES OF SHOE LEATHERS.

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PURPOSE OF INVESTIGATION.

There is great need of definite information on the wearing qualities of leather and on the effect of tannage, grease, loading materials, and the kind of hide used upon its serviceability and adaptability to the many operations to which leather is subjected in making various articles. Wearers of shoes need such knowledge to enable them to buy economically; tanners need it to enable them to make high-grade leather and to use their raw materials to the best advantage and at the lowest cost.

During the World War innumerable questions arose as to which leathers were best suited to certain purposes and as to what factors determined their suitability. In practically no case, on either side of the Atlantic Ocean, could a clear-cut, definite answer be given. The entrance of the United States into the war offered an excellent opportunity to conduct on a large scale systematic experiments with shoe leathers, the Army training camps providing large numbers of men who lived under fairly uniform conditions.

Accordingly, in July, 1919,[2] a very comprehensive study of the wearing qualities of leather was undertaken by the Bureau of Chem-

[1] The wearing experiments herein reported were conducted jointly by the United States Department of Agriculture and the United States War Department. The leather industry gave valuable cooperation in preparing leathers and in supplying information on tanning processes. Acknowledgment is made especially to Brig. Gen. A. L. Smith, W. D. McKissick, Capt. G. C. Bosson, and Capt. R. L. McAndrews, of the War Department, and to C. P. Keighley and B. A. Corbin & Son Co. for their interest and assistance.

[2] The plans for this work were outlined in 1917 and later revised and approved by representatives of the War Department and of the industry.

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istry of the United States Department of Agriculture. This investigation included studies of shoe soles made from the following materials: (1) Sole leather of typical tannages (oak bark, chestnut wood, and hemlock bark); (2) sole leather unloaded and loaded with glucose and epsom salts; (3) rolled and unrolled sole leather; (4) low and high oiled sole leather; (5) sole and belting leather; (6) vegetable-tanned sole leather, chrome-tanned sole leather, and fiber soles; (7) waxed and unwaxed chrome-tanned sole leather; (8) sole leather subjected to other treatments of minor importance. Several types of upper leather and of Army shoes were also included.

PLAN OF INVESTIGATION.

SELECTION OF MATERIAL.

Hides.—In order to secure a reasonable control of the variations caused by differences in hides, nearly all of the vegetable-tanned sole leathers were made from green salted hides. A few lots, taken for comparison, were made from dry hides. Eighteen of the 34 lots of vegetable-tanned sole leather were made from "Texas" hides, which were used whenever possible.

Leathers.—All leathers were selected and marked by an experienced trade man representing the War Department and by representatives of the Bureau of Chemistry, who also obtained detailed information on the history of the leathers. Thirty-four lots of vegetable-tanned sole leather were secured from 19 tanners, 3 lots of vegetable-tanned belting leather from 3 belting concerns, 2 lots of unwaxed chrome-tanned sole leather from 2 tanneries, and 6 lots of waxed chrome-tanned sole leather from 4 tanners. With the exception of 2 broken lots, each lot of sole leather consisted of 10 bends. At the time these experiments were planned the question of the best upper leather for continuous, heavy outdoor service was a very live one. Hence, for general observations on upper leathers, the chief types of cowhide upper leathers were included. These consisted of (1) one lot of bark-tanned leather, flesh finish; (2) two lots of stuffed chrome-tanned leather, grain finish; (3) one lot of fat-liquored chrome-tanned leather, grain finish; and (4) four lots of retanned chrome leather, two flesh finish and two grain finish.

Fiber soles.—From the most prominent brands of fiber soles, 96 pairs, representing four makes, were chosen.

PREPARATION OF MATERIAL.

To eliminate as far as possible the difference in wearing quality due to the section of the hide,[3] the soles were taken from only two definite sections of each bend, one pair at the shoulder end, at a point directly above the "break" in the hide back of the forelegs, and the other pair at the butt end, directly above the "break" in front of the hind legs. These two sections, representing the extremes of the bend, were fixed on this physiological basis rather than by a stated measurement from a given point in the bend.

Each lot of leather was given a serial number, the bends of each lot were numbered from 1 to 10, and each sole was designated by the number 1, 3, 4, or 6 (Fig. 1). Thus a sole numbered 2–4–1 came from

[3] J. Amer. Leather Chem. Assoc. (1918), *13*: 86.

lot 2, bend 4, position 1. Soles 1 and 3 constituted a pair from the shoulder end, and soles 4 and 6 a pair from the butt end. The toes were always pointed toward the head end of the hide and the left sole was always cut next to the backbone.

Piece 2 was cut out between soles 1 and 3, and piece 5 between soles 4 and 6, for use in further developments of machine tests on the wearing quality and other physical properties of leather. These machine pieces were numbered and marked for direction with a diagonal line connecting the edge nearer the backbone with that toward the butt.

The trimmings around the soles and test pieces were used to make up composite samples of the original leather for chemical analysis.

The soles were cut out with a die and permanently stamped with the complete identification number in the shank on the grain side, and in the heel and back of the ball on the flesh side. After the soles had been leveled, the average thickness of the ball of each sole was recorded in thousandths of an inch. When they had been inspected

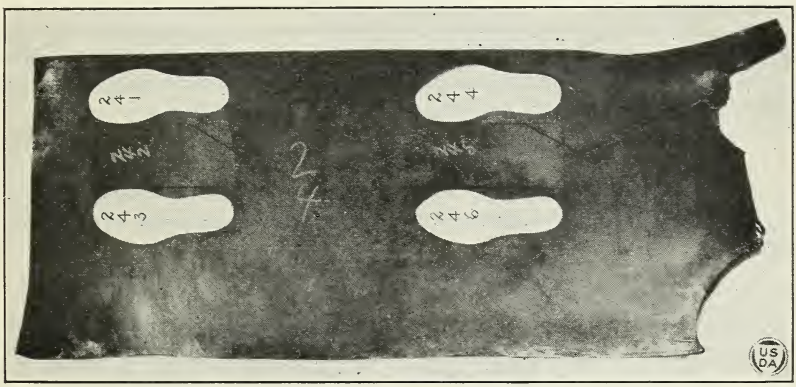

FIG. 1.—Identification of soles.

by Army inspectors, the soles were made up into Army shoes by a New England shoe factory, running on an Army shoe contract.

The shoes were made according to War Department Specifications 412–2–9, that is, with full double soles on the Munson last, without hobnails, heelplates, or toeplates. Other types of shoes, from regular contract delivery, were included, such as specifications 1352 (marching tan, practically identical with 412–2–9, but on a rocker last) and specifications 1258 (russet dress shoe, single sole and Munson last).

Each shoe was stamped near the top of the quarter with an identification number. Altogether there were about 2,000 pairs of shoes. Of these 967 pairs were soled with the test leathers as follows: 677 pairs with vegetable-tanned sole leathers; 60 pairs with vegetable-tanned belting leathers; 134 pairs with chrome-tanned sole leathers; and 96 pairs with fiber.

WEARING CONDITIONS.

It was planned originally to distribute the shoes between a camp in Ohio, where the climate is comparatively wet, and camps in Texas, which has a very dry climate. Rapid demobilization at the Ohio camp, however, necessitated a change, so that most of the shoes upon which reports were received were worn in Texas and New Mexico.

The shoes were issued only to privates and were carefully fitted by Army officers. Each private kept a card record of the wear of his shoes, which was checked from time to time when the shoes were inspected.

The worn-out shoes were sent to Washington for final inspection. After the observations and ratings from this inspection had been recorded, the worn soles were removed in the Bureau of Chemistry for examination, analysis, and comparison with the original leathers.

RESULTS OF INVESTIGATION.

Because of the frequent changes in officer personnel and the rapid discharge at the close of the war of soldiers, to many of whom experimental shoes had been issued, much information was lost. The results therefore are not as complete as they otherwise would have been. For this reason it is inadvisable to base detailed conclusions on this work, or to stress the direct comparison of one lot of leather with another.

Certain broad, general conclusions, however, appear to be warranted for the wear conditions of these experiments, especially in view of the fact that these tests included more shoes, more kinds of leather, and more comparisons than any other similar experiments

CONDITION OF WORN LEATHER.

All statements concerning upper leathers, types of shoes, and fiber soles are based on the ratings given in the inspection of the worn shoes.

Upper Leathers.

At the end of the investigation the upper leathers of all types were in good condition, only an occasional shoe upper showing material wear. However, the bark-tanned uppers were decidedly hard and stiff, 58 per cent being rated as too stiff or hard to wear with comfort or safety. This condition, while in general agreement with European observations in the field, may have been accentuated by the fact that the experiments were conducted in a section where the soil contains free alkali and where the climate is very dry.

There was practically no difference between grain-finished stuffed chrome-tanned and fat-liquored chrome-tanned upper leathers. These leathers were pliable and retained well their soft dressed feel. The retanned chrome leather (chrome tanned and slightly retanned with vegetable tanning materials) seemed to be the best of all in pliability and softness, but was somewhat dryer or harsher than the stuffed or fat-liquored chrome-tanned leathers. The grain-finish retanned chrome leather had a better appearance than the flesh-finish leather and seemed to be more pliable and mellow. The upper leathers ranged from 2.3 to 3 millimeters in thickness. Leather of this weight is too heavy and thick for uppers, except possibly for winter trench wear or heavy outdoor work.

The experiments were not continued long enough to determine the actual wearing quality of the upper leathers. It was evident, however, that, with reasonable care, upper leathers from 2.3 to 3 millimeters thick would outwear three or more soles, and that these typical American upper leathers were capable of giving long service.

The serviceability of such heavy upper leather therefore is of less concern than that of sole leather.

Soling Material.

Fiber soles of the kinds used were not suited for the wear conditions to which they were subjected, owing to the development of defects, such as ripping, breaking, and chipping, which, although important in the consideration of a satisfactory bottom stock, should here be distinguished from the property of resistance to the abrasive action of wear.

Ripping from the stitches was a common fault of the fiber soles, some lots being worse than others in this respect. Frequently the soles ripped loose or broke off to the heel or shank when the edge of the sole wore through the stitches. One lot of fiber soles were stitched on by a representative of the firm supplying them and the others by a plant foreman with much factory experience with fiber soles.

Many of the fiber soles of all of the makes bulged—that is, they became larger in area than the middle sole. Small pieces also frequently chipped off from the soles of two lots.

The results in Table 1, expressed as percentage of the number of shoes inspected, show clearly the superiority, in the features just discussed, of the leather soles over the fiber soles used. The data on fiber soles are given also by individual lots to show that not all of them developed the defects to the same extent.

Table 1.—*Proportion of soles that developed imperfections during tests.*

Soling material.	Ripped or broken off to heel or shank.	Short rip only.	Bulged.[1]	Chipped or broken-off pieces.[1]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Vegetable-tanned sole leather	.....	7.3	.....	.....
Waxed and unwaxed chrome-tanned sole leather	.....	17.6	.....	.....
Fiber:				
All lots	23.7	16.1	28.8	8.3
Lot 01	13.8	22.2	27.7	16.5
Lot 02	4.2	12.5	20.9	20.9
Lot 03	11.5	11.5	38.4	.....
Lot 04	59.3	15.6	28.1	.....

[1] Observations on bulging and chipping, of course, could not be made on shoes from which the soles were entirely ripped or broken.

Because of excessive toe wear and severe conditions of service, any ripping, chipping, or bulging tendencies were accentuated. It is probable, therefore, that the percentage of failures for fiber soles would be decidedly lower for civilian wear, particularly in cities. This point and the possibility that fiber soles, being entirely fabricated products, might be so modified as to overcome the defects discussed should be borne in mind, especially since the wear data (p. 8 and fig. 2) show for the fiber soles which did not come off during the test a very high degree of resistance to wear, placing them second only to unwaxed chrome sole leather.

The fiber soles were backed with a full middle sole of leather. While not the usual construction, it seems a desirable one, particularly from the standpoint of the comfort of the wearer.

Types of Shoes.

Many of the shoes examined showed excessive toe wear. Many were worn through to the middle sole at the tip before the rest of the sole showed much wear. When worn to this extent, the shoe, of course, should be repaired, which would mean that the service of most of the original sole would be lost. Furthermore, most people having such shoes continue to wear them until they are worn through the middle sole and welt and sometimes until they are worn down on the uppers at the toe. This means not only that for some time the feet have not had proper protection, but that the time, labor, and cost of repair to shoes so worn would be almost prohibitive and that much leather would be wasted. Plate I shows excessive toe wear and its consequences.

This is an important matter. Since all the shoes had been carefully fitted to the soldiers, it is not probable that the excessive wear at the toe can be ascribed to the fact that the shoes were too short. It appears rather that this condition, which was far too general to be attributed to the personal factor, was occasioned by the type or construction of the shoes. This view is supported by the results reported in Table 2.

Table 2.—*Toe wear of different types of shoes.*

Specifications.	Number of shoes.	Shoes showing undue toe wear.
		Per cent.
412–2–9	808	61.5
1352	57	45.6
1258	73	24.6

Specifications 412–2–9 require two full soles on the Munson last; specifications 1352 are practically the same as 412–2–9, except that the shoes are made on a slight rocker last; specifications 1258 call for only one outsole on the Munson last. It is believed that the excessive toe wear is due to the stiffness of the shoes caused by the double shank which permits the shoes to bend but little. Thus, in walking the weight of the body is concentrated at the extreme end of the sole, instead of being distributed over a greater area at the ball. The slight rocker effect in specifications 1352 has a tendency to overcome this, while with specifications 1258 the single sole gives greater flexibility to the shoe and materially reduces the wearing action at the toe. It is understood that the tendency to excessive wear at the toe has been overcome in the Army shoe by reducing the thickness in the shank to one sole only, thereby giving the flexibility previously lacking.

Full double soles, that is double soles in the shank and under the heel, should be used only with some means of increasing materially the flexibility of the sole in the shank. Shank stiffness, with consequent rapid wear and waste of leather, also may be partly overcome by making shoes or boots on a pronounced "rocker" last. The most effective construction for securing the protection and service of a double-sole shoe, however, would seem to be a single-sole shank and a double sole at the ball, in other words, a half-sole tap on top of a full sole.

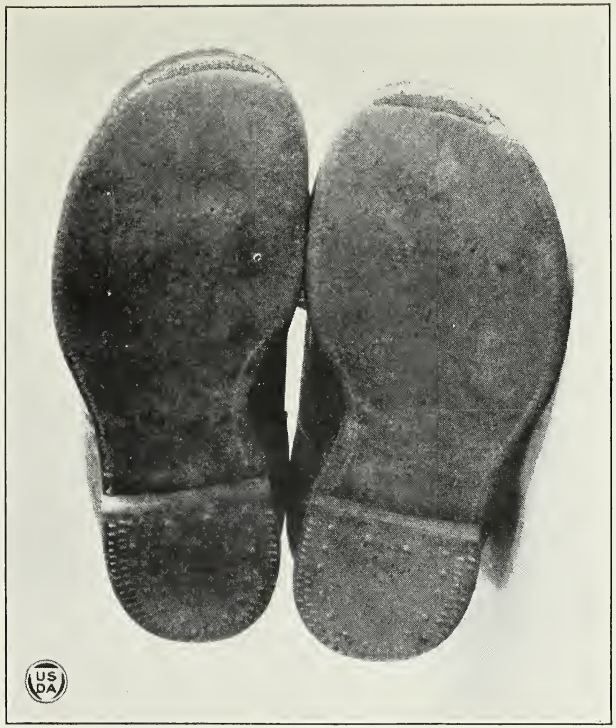

FIG. 1.—Effect of stiff shanks. The first sole is soon worn through at the tip. Usually shoes in this condition should be repaired at once, although most of the sole is still good.

FIG. 2.—Effect of stiff shanks and continued wear. These shoes are worn through the middle sole and welt and often into the upper. This not only reduces the serviceability of the shoes, but also gives the foot poor protection and adds greatly to the cost of repair.

FIG. 1.—Burnt shanks caused by overheating leather when wet.

FIG. 2.—Burnt middle sole. The outer sole apparently is still in good condition.

Burnt Soles.

That serious damage may be done quickly in drying out wet shoes is not generally known, and it is difficult to drive home the necessity of extreme care with wet shoes. Wet leather will certainly burn if it is placed close to a fire or other source of heat where the heat is greater than the hand can bear. As the experiments here reported were conducted mainly under very dry conditions, there were only a few cases of burnt soles. During the war, however, the Bureau of Chemistry was frequently called on to confirm the opinions of experienced Army officers that the condition of a shoe was the result of burning while wet. It is difficult for inexperienced persons to realize that the fused, vitreous, lustrous, and brittle mass on the bottom of a shoe is the result of burning wet leather when it was exposed to heat but little greater than the hand can bear. Plate II, Figure 1, shows burnt shanks which have lost all the life and properties of good leather.

Plate II, Figure 2, shows a shoe (left), in this case with a fiber outsole, in apparently good condition, with no evidence of having been mistreated, and the same shoe (right) with the outer sole turned back to reveal a badly burned, "fused" place in the middle sole. Cases similar to this, in which even the middle of a leather outsole has been burned and fused while the outer surface of the sole showed very few signs of heating, have been observed.

EFFECT OF CERTAIN FACTORS ON WEAR OF SOLE LEATHER.

The wear data for each shoe were tabulated in detail and carefully analyzed. The data for each sole have been calculated to "days wear per 9 irons" [4] by proportion from the thickness worn away and the number of days each pair of shoes was worn. The extreme wear at the toe was disregarded. Unless a hole was worn through some other part of the sole before it became necessary to recall the shoes, the thinnest part of the sole was measured and the leather worn away was determined from the original thickness of the sole. The loss in thickness thus obtained was used in the calculation to "days wear per 9 irons." Data for the soles from shoes which did not show appreciable wear were discarded. Averages were taken from the detailed individual data which are too voluminous to be included here.

Effect of Tannage.

The sole leathers used in these experiments were classified as "oak," "hemlock," and "chestnut," depending on whether oak bark, hemlock bark, or chestnut wood extract predominated, making at least 60 per cent of the tanning formula by which the leathers were tanned. Only the regular trade brands of leathers are included in these comparisons. Special leathers are compared on pages 9 to 11.

Oak bark tannages.—Data from 126 soles cut from 7 lots of leather were summarized. All the hides were short-hair hides. They were classed as follows: 2 lots of "Texas"; 1 lot of "butt branded" and "Texas"; 1 lot of "butt branded"; 2 lots of "Colorado"; and 1 lot of "small packer." The number of days the leathers were in the yard

[4] The iron, a unit of thickness used by the leather trade, is equivalent to one forty-eighth inch.

being tanned varied from 100 to 185, with an average of 151. The average days wear per 9 irons varied per lot from 59 to 87. The average days wear per 9 irons for all lots was 78.1.

Chestnut wood extract tannages.—Data from 175 soles cut from 8 lots of leather were summarized. All the hides were short-hair hides. They were classed as follows: 6 lots of "Texas"; 1 lot of "Colorado"; and 1 lot of "butt branded" and "Colorado." The number of days the leathers were in the yard being tanned varied from 55 to 140, with an average of 92. The average days wear per 9 irons varied per lot from 71 to 97. The average days wear per 9 irons for all lots was 80.

Hemlock bark tannages.—Data from 103 soles cut from 5 lots of leather were summarized. Three of the lots consisted of short-hair hides. The hides were classed as follows: 2 lots of "Texas"; 1 lot of "dry Texas"; 1 lot of dry "Buenos Aires"; and 1 lot of "South American packer." The number of days the leathers were in the yard being tanned varied from 85 to 120, with an average of 99. The average days wear per 9 irons varied per lot from 62 to 102, these extremes being given by the two dry hide lots. The average days wear per 9 irons for all lots was 79.3. The average days wear per 9 irons for green salted hides was 78.5.

Oak belting tannages.—Data from 62 soles cut from 3 lots of leather were summarized. All the hides were "native steers." The average days wear per 9 irons varied per lot from 82 to 88. The average days wear per 9 irons for all lots was 85.5.

Waxed chrome tannages.—Data from 82 soles cut from 5 lots of leather were summarized. The hides were classed as follows: 1 lot of "Texas"; 1 lot of "Maral bulls"; 2 lots of "domestic bulls"; and 1 lot of "dry China buffalo" or "Java." The average days wear per 9 irons varied per lot from 80 to 118. The average days wear per 9 irons for all lots was 102.

Unwaxed chrome tannages.—Data from 31 soles cut from 2 lots of leather were summarized. The hides were classed as "domestic bulls." The average days wear per 9 irons was 124 for one lot and 128 for the other. The average days wear per 9 irons for both lots was 125.8.

Fiber soles.—Data from 81 soles from 4 makes were summarized. The average days wear per 9 irons varied per lot from 102 to 144. The average days wear per 9 irons for all makes was 121.6.

Most of the soles were worn in a very dry climate. The percentage worn in Texas and New Mexico, where there was practically one rainfall a month, was as follows: Oak-bark-tanned leathers, 79.5; chestnut-wood-extract-tanned leathers, 85; hemlock-bark-tanned leathers, 75; oak-bark-tanned belting leathers, 80.5; waxed chrome-tanned leathers, 69.5; unwaxed chrome-tanned leathers, 80.5; fiber soles, 63.

There is no appreciable difference in the wear of the four classes of vegetable-tanned leathers, except that the soles cut from belting leathers wore a few days longer than those from the other leathers. Soles from the chrome-tanned leathers wore decidedly longer, those from the unwaxed chrome-tanned leathers wearing longer than those from any other tannage. The fiber soles wore well except for the imperfections previously discussed.

The results with the three classes of sole leather would seem to indicate that the time of tanning—that is, the time the leathers were

in the tan liquor—is not a material factor in the wear, provided the leathers have been well tanned. The time of tanning varied from an average of 151 days for oak to 92 days for chestnut, hemlock-tanned sole leather being intermediate, with an average of 99 days.

Effect of Glucose and Epsom Salts Content.

To study the effect of glucose and epsom salts on the wear of sole leather several tanners prepared special lots in which the glucose and epsom salts content differed from that in leather of their regular tannages, the other factors being kept as constant as possible. A comparison of the wear of these leathers is made in Table 3.

Table 3.—*Effect of glucose and epsom salts content on wear of sole leather.*

Lot No.	Description of leathers.	No. of soles.	Composition of original leather (moisture-free basis).									Average days wear per 9 irons.
			Total ash.	Petroleum-ether extract.	Uncombined tannin.	Non-tannins.	Water solubles.	Epsom salts.	Glucose.	Hide substance.	Combined tannin.	
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
	Oak tannage:											
1	Regular	18	1.46	3.37	14.59	12.91	27.50	3.11	2.61	40.25	28.75	85
2	Special (same as lot 1 except lightly rolled and low in glucose and salts).	18	.31	4.65	13.11	6.50	19.61	.12	.37	44.43	31.20	75
9	Special	20	.85	1.93	11.84	15.69	27.53	2.77	7.79	40.21	30.19	59
8	Regular (same as lot 9 except low in glucose and salts).	18	.35	1.89	13.59	6.84	20.43	.12	1.11	44.66	32.89	59
	Chestnut tannage:											
13	Regular	26	.72	1.78	11.39	12.52	23.91	1.49	5.53	45.00	29.15	82
14	Special (same as lot 13 except lower in glucose)	22	.70	3.85	12.79	8.79	21.58	1.79	2.75	45.58	28.85	72
24	Regular	28	2.50	1.79	16.56	11.94	28.50	[1].73	4.11	44.56	24.89	84
25	Special (same as lot 24 except highly oiled and low in glucose and salts).	20	.54	7.48	14.54	6.50	21.04	.55	.33	45.56	25.67	80
	Hemlock tannage:											
29	Regular	26	2.02	2.33	14.51	14.95	29.46	4.54	6.54	39.95	28.08	72
30	Special (same as lot 29 except unbleached and low in glucose and salts)	16	.36	2.62	13.85	4.68	18.53	.27	.22	48.41	30.32	73
32	Regular	18	1.59	2.20	14.47	13.87	28.34	4.15	4.82	38.86	30.21	86
33	Special (same as lot 32 except low in glucose and salts).	20	1.19	2.25	14.79	10.92	25.71	2.09	2.86	40.79	31.11	73

[1] Also contained 1.73 per cent of barium chlorid.

Differences in composition of certain other regular brands of leather permit another comparison showing the effect of the glucose and epsom salts content on wear.

Data secured on 90 soles from 5 lots, consisting of only regular brands of sole leather having less than a total of 3 per cent of glucose and epsom salts, were assembled. The total glucose and epsom salts content varied from 1.23 to 2.99 per cent and averaged 1.95 per cent. The average days wear per 9 irons for all lots was 80.

Data secured on 249 soles from 12 lots, consisting of only regular brands of sole leather having more than a total of 7 per cent of glucose and epsom salts, were assembled. The total glucose and epsom salts content varied from 7 to 11.08 per cent and averaged 8.92 per cent. The average days wear per 9 irons for all lots was 80.

Averages from Table 3 alone indicate 8 per cent greater wear for the loaded leathers. In this same comparison, however, two sets

(lots 8 and 9 and lots 29 and 30) having the greatest differences in glucose and epsom salts content show no significant difference in wear. In the second comparison, also, no difference in wear is shown.

Considering all results, the indications are that, within the limits noted, the content of glucose and epsom salts does not materially affect the wear of soles in a dry climate. Had the tests been conducted in a damper climate, the result might have been quite different.

Effect of Rolling Leather.

The wearing qualities of rolled leather from regular brands were compared with those of unrolled leather from the same brands. The thickness of the rolled leathers was measured after rolling.

Table 4.—*Effect of rolling on wear of sole leather.*

Lot No.	Description of leathers.	No. of soles.	Composition of original leather (moisture-free basis).									Average days wear per 9 irons.
			Total ash.	Petroleum-ether extract.	Uncombined tannin.	Nontannins.	Water solubles.	Epsom salts.	Glucose.	Hide substance.	Combined tannin.	
	Oak tannage:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
5	Regular	16	1.01	2.03	16.56	9.39	25.95	1.37	1.08	40.04	31.85	77
6	Same as lot 5 except unrolled	16	.94	2.18	14.89	8.39	23.28	1.47	1.10	40.45	33.87	68
	Chestnut tannage:											
16	Regular	20	1.14	2.75	15.77	12.29	28.06	3.19	5.03	41.23	27.84	73
17	Same as lot 16 except unrolled	14	.94	2.34	15.82	9.30	25.16	3.28	3.13	42.21	30.19	55
20	Regular	20	1.48	2.38	13.44	16.32	29.76	3.71	6.90	44.05	23.64	71
21	Same as lot 20 except unrolled	24	1.63	2.56	13.35	16.35	29.70	4.02	6.28	42.50	25.11	69

Table 4 shows approximately 16 per cent longer wear for the rolled leathers per unit thickness of 9 irons. In other words, a well-rolled leather will outwear the corresponding unrolled leather, thickness for thickness. The results do not mean that rolling a given piece of leather increases its wear by about 16 per cent. Rolling compresses the leather. Consequently a given thickness of rolled leather contains more substance than unrolled leather of the same thickness, and, other things being equal, it should wear longer. The decrease in thickness caused by rolling varies in practice. For the leathers listed in Table 4 the average decrease from rolling was 12.4 per cent of the average original thickness.

While the expression of wear results on a unit thickness basis does not take into account the thickness changes resulting from processes in the tanning and finishing, it is the only feasible method which permits a comparative summary of data and is in harmony with the trade practice of buying and selling leather on the "iron" basis.

The wear data of the leathers reported in Table 4 have also been calculated back to days wear for the actual original thicknesses of the unrolled and rolled leathers, respectively. On this basis no significant difference in wear is shown, the average figures being 80.2 days for the unrolled and 81.2 days for the rolled leathers. This indicates that rolling does not affect the wear of a piece of sole leather. There is, however, always the possibility that excessive rolling may break down the fiber, thus decreasing the wear resistance of the leather. Or conditions of service may be such, for example a damp climate, that rolling increases the wear by imparting to the leather a greater resistance to the penetration of water.

Effect of Oiling Leather.

As a rule, American sole leathers contain but little oil or grease. One of the problems on which it was planned to throw some light in this investigation was the effect on the wearing quality of leather of materially increasing its oil or grease content.

Table 5 shows the effect on wear of increasing slightly the oil content in certain leathers.

Table 5.—*Effect of oiling on wear of sole leather.*

Lot No.	Description of leathers.	No. of soles.	Composition of original leather (moisture-free basis).									Average days wear per 9 irons.
			Total ash.	Petroleum-ether extract.	Uncombined tannin.	Nontannins.	Water solubles.	Epsom salts.	Glucose.	Hide substance.	Combined tannin.	
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
	Oak tannage:											
10	Regular	20	1.83	2.76	13.71	14.17	27.88	2.90	4.40	38.21	30.70	87
11	Same as lot 10 except not bleached or drummed and containing more oil	20	1.08	4.79	14.40	10.10	24.50	1.25	1.66	39.30	31.15	70
	Chestnut tannage:											
13	Regular	26	.72	1.78	11.39	12.52	23.91	1.49	5.53	45.00	29.15	82
15	Same as lot 13 except containing less glucose and more oil	22	.76	4.58	13.28	8.60	21.88	1.75	2.47	45.34	28.08	86
24	Regular	28	2.50	1.79	16.56	11.94	28.50	[1].73	4.11	44.56	24.89	84
25	Same as lot 24 except low in glucose and epsom salts and high in oil	20	.54	7.48	14.54	6.50	21.04	.55	.33	45.56	25.67	80

[1] Contained also 1.73 per cent of barium chlorid.

The results in Table 5 show very little difference in wear between a sole leather having the usual oil content and one having a somewhat higher oil content. Eight per cent greater wear is shown for the leather having the usual oil content. This might be decidedly different if the shoes had been worn in a wet climate. The difference between the oil contents of the two classes of leather is not great enough to warrant a definite conclusion.

Effect of Acid Tannage.

In so-called acid tannages the hides are plumped with sulphuric acid before being tanned or in the rockers, rather than with the natural organic acids of the tanning materials, as is the case with nonacid tannages. Comparatively little acid sole leather is now being made.

Table 6 shows the effect of acid tannage on the wear of chestnut-tanned leathers.

TABLE 6.—*Effect of acid tannage on wear of sole leather.*

Lot No.	Description of leathers.	No. of soles.	Composition of original leather (moisture-free basis).									Average days wear per 9 irons.
			Total ash.	Petroleum-ether extract.	Uncombined tannin.	Nontannins.	Water solubles.	Epsom salts.	Glucose.	Hide substance.	Combined tannin.	
	Chestnut tannage:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
18	Regular, nonacid...	16	2.47	1.35	15.52	14.53	30.05	3.04	4.01	41.74	26.65	97
19	Same as lot 18 except acid.....	24	2.09	2.29	15.76	15.81	31.57	2.27	5.19	37.80	28.12	82
20	Regular, nonacid...	20	1.48	2.38	13.44	16.32	29.76	3.71	6.90	44.05	23.64	71
22	Same as lot 20 except acid.....	24	1.29	1.98	18.20	14.55	32.75	2.84	6.05	38.82	26.30	69

The results in Table 6 indicate that nonacid-tanned leather wears slightly longer than leather of an acid tannage. The ratio of combined tannin to hide substance, or the "degree of tannage," is somewhat higher for the acid-tanned leathers, being 74.4 and 67.8 for the acid lots 19 and 22 and 63.9 and 53.6 for the nonacid lots 18 and 20. It is the general opinion of tanners that plumping the hide with sulphuric acid hastens the tanning and also causes more tannin to combine with the hide.

EFFECT OF POSITION IN BEND.

The section of the hide from which a sole is cut plays an important part in the wearing quality of the shoe. In fact, soles cut from different sections of a hide generally show greater differences in wear than soles cut from the same section of different lots of leather made from the same class of hides and of the same tannage. Experience has fully established this fact in a general way, and experiments have confirmed it on a somewhat comparative basis.[5] Since the bend represents the choice section of the hide, it is to be expected that soles cut from the extreme parts of the bend will not show great variation in wearing quality. Definite information on how great this difference is was sought in this investigation.

The average days wear per 9 irons for all soles from the shoulder end of the bends is 79 and that from the butt end is 85. Out of 43 lots compared, the soles cut from the butt section of 25 lots wore longer.

COMPOSITION OF ORIGINAL AND WORN SOLE LEATHERS.

The soles of the worn shoes were removed and thoroughly cleaned by brushing. For each lot of sole leather composite samples were made from the ball and from the heel seat of only the well-worn soles. A strictly comparable composite sample of the original leather was also made. For the first six lots separate composite samples of the original leather from the shoulder and also from the butt ends of the bend were analyzed, as a matter of interest in connection with the effect of position in the hide upon the composition of the leather. The official methods of the American Leather Chemists' Association were followed in making the analyses. The results of these analyses, calculated to the moisture-free basis, are given in Table 7.

[5] J. Amer. Leather Chem. Assoc. (1918), *13;* 86.

TABLE 7.—*Composition of original and worn sole leathers.*

Lot No.	Description of leathers.	Sample.	Fluorescence.	Composition (moisture-free basis).												Average days wear per 9 irons.
				Total ash.	Insoluble ash.	Petroleum-ether extract.	Uncombined tannin.	Non-tannins.	Water solubles.	Epsom salts.	Glucose.	Combined tannin.	Hide substance.	Degree of tannage.	Acidity P. & S.	
		Original for:		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	
1	Oak tannage, regular; small packer hides; bleached; drummed; tanned 130 days.	Shoulder end	Decided	1.66	0.11	3.14	14.80	13.74	28.54	3.47	3.06	29.61	38.60	76.71	0.10	
		Butt end	do	1.42	.13	3.38	14.61	12.32	26.93	2.77	2.35	27.47	42.09	65.26	.04	
		Worn soles	do	1.46	.13	3.37	14.59	12.91	27.50	3.11	2.61	28.75	40.25	71.43	.07	
		Heel seats of worn soles	do	1.63	.30	6.23	13.39	13.16	26.55	3.37	3.23	28.18	38.74	72.74	.16	
		Balls of worn soles	do	3.54	1.18	4.62	15.39	13.15	28.54	2.30	2.64	26.04	39.62	65.72	−.75	85
		Original for:														
2	Oak tannage, special; corresponding to lot 1 except lightly rolled and bleached; not drummed; low in glucose and epsom salts.	Shoulder end	do	.35	.10	4.66	13.36	6.75	20.11	.14	.22	31.74	43.39	73.15	.23	
		Butt end	do	.28	.10	4.29	12.95	6.71	19.66	.00	.24	30.25	45.70	66.19	.21	
		Worn soles	do	.31	.11	4.65	13.11	6.50	19.61	.12	.37	31.20	44.43	70.22	.20	
		Heel seats of worn soles	do	.79	.15	5.66	13.21	8.62	21.83	.98	1.37	30.55	41.81	73.06	.25	
		Balls of worn soles	do	3.68	1.46	5.31	13.95	11.82	25.77	1.38	2.13	26.81	40.65	65.95	−.60	75
		Original for:														
3	Oak tannage, regular; Texas hides; bleached; not drummed; low in glucose and salts; tanned 185 days.	Shoulder end	do	.50	.11	2.35	14.72	11.08	25.80	.21	1.10	27.90	43.84	63.64	.27	
		Butt end	do	.42	.10	1.86	14.24	10.18	24.42	.64	1.02	27.00	46.62	57.92	.25	
		Worn soles	do	.56	.09	2.42	14.50	10.80	25.30	.77	1.06	28.57	43.62	65.50	.43	
		Heel seats of worn soles	do	.71	.14	3.63	12.67	11.55	24.22	1.15	1.80	28.99	43.02	67.39	.47	
		Balls of worn soles	do	3.47	1.22	3.40	13.80	14.76	28.56	1.88	2.47	25.79	41.03	62.86	−.42	85
		Original for:														
4	Oak tannage, regular; Colorado hides; bleached; not drummed; low in glucose and salts; tanned 150 days.	Shoulder end	do	.46	.12	2.27	15.46	8.32	23.78	.75	.63	29.48	44.35	66.47	.22	
		Butt end	do	.40	.10	2.15	14.45	8.07	22.52	.71	.41	29.27	45.96	63.69	.16	
		Worn soles	do	.43	.12	1.94	15.11	7.72	22.83	.59	.46	30.47	44.64	68.26	.20	
		Heel seats of worn soles	do	.81	.22	3.75	13.94	9.48	23.42	.78	1.33	28.50	44.11	64.61	.16	
		Balls of worn soles	do	2.74	1.10	2.68	13.83	12.17	26.00	1.56	2.16	28.22	42.00	67.19	−.49	74
		Original for:														
5	Oak tannage, regular; butt-branded hides; bleached; drummed; low in glucose and salts; tanned 100 days.	Shoulder end	Strong	1.30	.15	2.26	16.53	9.71	26.24	1.73	1.26	33.09	38.26	86.49	−.06	
		Butt end	do	1.00	.15	1.93	15.44	8.97	24.41	1.37	1.21	32.72	40.79	80.22	.03	
		Worn soles	do	1.01	.13	2.03	16.56	9.39	25.95	1.37	1.08	31.85	40.04	79.55	.00	
		Heel seats of worn soles	do	1.23	.20	3.68	15.89	10.22	26.11	1.84	1.72	30.38	39.63	76.66	.00	
		Balls of worn soles	do	2.99	.93	3.43	16.49	13.41	29.90	2.21	2.63	28.73	37.01	77.63	−.42	77
		Original for:														
6	Oak tannage, special; corresponding to lot 5 except set out but not rolled.	Shoulder end	do	1.00	.20	2.65	14.08	8.17	22.25	1.20	1.14	35.51	39.39	90.15	.11	
		Butt end	do	.81	19	2.25	14.62	8.29	22.91	1.11	1.03	33.70	40.95	82.30	.20	
		Worn soles	do	.94	.22	2.18	14.89	8.39	23.28	1.47	1.10	33.87	40.45	83.73	.09	
		Heel seats of worn soles	do	1.54	.32	2.36	14.15	10.95	25.10	2.74	2.18	32.16	40.06	80.28	.11	
		Balls of worn soles	do	2.92	1.34	2.74	14.45	10.33	24.78	1.52	1.78	31.26	39.88	78.39	−.55	68

TABLE 7.—*Composition of original and worn sole leathers*—Continued.

Lot No.	Description of leathers.	Sample.	Fluorescence.	Composition (moisture-free basis).												Average days wear per 9 irons.
				Total ash.	Insoluble ash.	Petroleum-ether extract	Uncombined tannin.	Non-tannins.	Water solubles.	Epsom salts.	Glucose.	Combined tannin.	Hide substance.	Degree of tannage.	Acidity P. & S.	
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	
7	Supposedly oak tannage, regular; Texas hides; not bleached; not drummed; low in glucose and salts; tanned 180 days.	Original for worn soles	None	0.22	0.16	1.47	13.61	6.08	19.69	0.53	0.26	32.24	46.44	69.42	0.25	
		Heel seats of worn soles	do	.72	.20	2.44	13.62	8.23	21.85	1.05	1.41	29.60	45.91	64.47	.14	
		Balls of worn soles	do	2.45	1.09	3.29	13.80	9.62	23.42	1.15	1.69	28.01	44.19	63.39	−.42	103
8	Oak tannage, regular; Colorado hides; not bleached; not drummed; low in glucose and salts; tanned 165 days.	Original for worn soles	Strong	.35	.13	1.89	13.59	6.84	20.43	.12	1.11	32.89	44.66	73.65	.09	
		Heel seats of worn soles	do	.90	.22	2.70	13.37	9.28	22.65	1.38	2.06	31.58	42.85	73.70	.03	
		Balls of worn soles	do	3.44	1.26	3.21	14.26	11.29	25.55	.88	2.47	28.17	41.81	67.38	−.58	59
9	Oak tannage, special; corresponding to lot 8 except high in glucose and salts.	Original for worn soles	do	.85	.14	1.93	11.84	15.69	27.53	2.77	7.79	30.19	40.21	75.08	.16	
		Heel seats of worn soles	do	1.19	.21	2.84	11.81	15.59	27.40	2.65	7.48	28.74	40.81	70.42	.22	
		Balls of worn soles	do	3.30	1.45	3.33	11.58	13.65	25.23	1.73	5.44	30.02	39.97	75.11	−.44	59
10	Oak tannage, regular; Texas and butt-branded hides; bleached; drummed; tanned 185 days.	Original for worn soles	Very strong	1.83	.45	2.76	13.17	14.71	27.88	2.90	4.40	30.70	38.21	80.35	.14	
		Heel seats of worn soles	do	1.69	.45	3.09	13.36	13.97	27.33	2.69	4.12	30.01	39.12	76.71	.25	
		Balls of worn soles	do	3.37	1.21	3.37	14.93	15.36	30.29	2.13	4.54	27.74	37.69	72.80	−.68	87
11	Oak tannage, special; Colorado hides; corresponding to lot 10 except unbleached, not drummed, and well oiled with a mixture of 50 per cent of cod and mineral oils.	Original for worn soles	do	1.08	.26	4.79	14.40	10.10	24.50	1.25	1.66	31.15	39.30	79.26	−.09	
		Heel seats of worn soles	do	1.31	.23	2.89	14.44	11.29	25.73	1.74	2.16	30.00	41.15	72.90	−.14	
		Balls of worn soles	do	3.26	1.29	3.38	14.76	12.64	27.40	1.91	2.61	28.70	39.23	73.16	−.85	70
12	Oak tannage, regular; Texas hides; unbleached; not drummed; low in salts and glucose; tanned 140 days.	Original for worn soles	Decided	.81	.21	2.35	16.29	12.67	28.96	.78	2.66	28.72	39.76	72.23	−.11	
		Heel seats of worn soles	do	1.16	.32	2.24	15.53	12.58	28.11	1.24	2.54	29.70	39.63	74.95	.71	
		Balls of worn soles	Strong	2.86	1.19	2.67	15.21	13.50	28.71	1.27	2.86	26.39	41.04	64.30	−.25	79

13	Chestnut tannage, regular; Texas hides; bleached; drummed; nonacid; high in glucose; tanned 125 days.	Original for worn soles	do	.72	.16	1.78	11.39	12.52	23.91	1.49	5.53	29.15	45.00	64.78	.94	
		Heel seats of worn soles	do	2.81	.18	2.28	10.68	11.96	22.64	1.57	4.89	29.46	45.44	64.83	.68	
		Balls of worn soles	do	4.43	1.38	2.75	11.40	12.45	23.85	1.93	4.82	28.37	43.65	64.99	−.05	82
14	Chestnut tannage, special; corresponding to lot 13 except less glucose and a little more oil.	Original for worn soles	do	.70	.14	3.85	12.79	8.79	21.58	1.79	2.75	28.85	45.58	63.30	.87	
		Heel seats of worn soles	do	1.06	.19	3.63	12.84	9.73	22.57	2.26	3.05	29.13	44.48	65.49	1.36	
		Balls of worn soles	do	2.97	1.35	3.70	12.46	11.52	23.98	1.70	3.57	28.00	42.97	65.16	.00	72
15	Chestnut tannage, special; corresponding to lot 13 except less glucose and more oil.	Original for worn soles	do	.76	.12	4.58	13.28	8.60	21.88	1.75	2.47	28.08	45.34	61.93	.36	
		Heel seats of worn soles	do	1.12	.21	3.78	13.10	10.57	23.67	1.50	3.02	27.37	44.97	60.86	.44	
		Balls of worn soles	do	3.24	1.14	3.70	12.67	11.53	24.20	1.58	3.25	26.56	44.40	59.82	−.11	86
16	Chestnut tannage, regular; Colorado and butt-branded hides; bleached; drummed; nonacid; high in salts and glucose; tanned 64 days.	Original for worn soles	Very slight	1.14	.12	2.75	15.77	12.29	28.06	3.19	5.03	27.84	41.23	67.52	1.03	
		Heel seats of worn soles	do	1.57	.27	3.00	14.50	13.06	27.56	3.66	5.33	28.87	40.30	71.64	1.10	
		Balls of worn soles	do	3.99	1.55	3.69	12.81	11.54	24.35	1.91	3.66	29.11	41.30	70.48	−.09	73
17	Chestnut tannage, special; corresponding to lot 16 except unrolled.	Original for worn soles	do	.94	.14	2.34	15.82	9.30	25.12	3.28	3.13	30.19	42.21	71.52	.82	
		Heel seats of worn soles	do	1.54	.26	3.66	14.00	11.33	25.33	2.61	4.29	29.46	41.29	71.35	.74	
		Balls of worn soles	do	4.13	2.20	3.20	12.87	11.13	24.00	2.16	3.27	29.09	41.51	70.08	−.11	55
18	Chestnut tannage, regular; Texas hides; bleached; drummed; nonacid; medium high in salts and glucose; tanned 90 days.	Original for worn soles	Slight	2.47	.21	1.35	15.52	14.53	30.05	3.04	4.01	26.65	41.74	63.85	1.25	
		Heel seats of worn soles	do	2.31	.32	2.18	15.02	13.65	28.67	2.77	3.97	27.32	41.51	65.82	.99	
		Balls of worn soles	do	3.45	1.10	3.47	14.07	12.57	26.64	1.94	3.42	27.04	41.75	64.77	.00	97
19	Chestnut tannage, regular; corresponding to lot 18 except acid tannage.	Original for worn soles	do	2.09	.22	2.29	15.76	15.81	31.57	2.27	5.19	28.12	37.80	74.39	1.59	
		Heel seats of worn soles	do	2.17	.25	4.16	16.09	15.58	31.67	2.56	5.13	26.23	37.69	69.59	1.45	
		Balls of worn soles	do	3.42	1.13	3.77	14.47	13.64	28.11	2.07	4.18	27.66	39.33	70.33	−.03	82
20	Chestnut tannage, regular; Texas hides; bleached; drummed; nonacid; high in salts and glucose; tanned 70 days.	Original for worn soles	Decided	1.48	.17	2.38	13.44	16.32	29.76	3.71	6.90	23.64	44.05	53.67	.60	
		Heel seats of worn soles	do	1.73	.20	3.71	13.05	16.02	29.07	3.01	6.82	24.00	43.02	55.79	1.03	
		Balls of worn soles	do	3.77	1.40	3.60	12.01	14.21	26.22	2.39	4.48	25.20	43.58	57.82	−.33	71
21	Chestnut tannage, special; corresponding to lot 20 except not rolled.	Original for worn soles	Slight	1.63	.13	2.56	13.35	16.35	29.70	4.02	6.28	25.11	42.50	59.08	1.34	
		Heel seats of worn soles	do	2.06	.29	3.16	13.79	16.43	30.22	4.00	6.41	24.49	41.84	58.53	.96	
		Balls of worn soles	do	3.92	1.50	3.42	13.77	15.23	29.00	3.23	5.25	23.48	42.60	55.12	−.09	69
22	Chestnut tannage, regular; corresponding to lot 20 except acid tannage.	Original for worn soles	Strong	1.29	.15	1.98	18.20	14.55	32.75	2.84	6.05	26.30	38.82	67.75	1.69	
		Heel seats of worn soles	do	1.68	.21	2.21	17.90	14.97	32.87	2.93	5.92	25.89	38.82	66.69	1.74	
		Balls of worn soles	do	3.59	1.90	2.89	15.34	12.67	28.01	1.81	4.30	27.62	39.58	69.78	.09	74

TABLE 7.—*Composition of original and worn sole leathers*—Continued.

Lot No.	Description of leathers.	Sample.	Fluorescence.	Composition (moisture-free basis).												Average days wear per 9 irons.
				Total ash.	Insoluble ash.	Petroleum-ether extract.	Uncombined tannin.	Non-tannins.	Water solubles.	Epsom salts.	Glucose.	Combined tannin.	Hide substance.	Degree of tannage.	Acidity P. & S.	
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	
23	Chestnut tannage, regular; Texas hides; bleached; dry dipped; acid; medium high in salts and glucose; tanned 70 days.	Original for worn soles	Decided	1.46	0.13	1.74	18.46	13.59	32.05	3.06	4.03	26.78	39.30	68.14	1.41	
		Heel seats of worn soles	do	1.71	.21	2.42	16.74	13.67	30.41	3.16	4.16	26.63	40.33	66.03	1.32	
		Balls of worn soles	do	3.78	2.03	2.87	16.45	12.70	29.15	2.39	3.14	25.82	40.13	64.34	—.03	91
24	Chestnut tannage, regular; Texas hides; not bleached; not drummed; nonacid; medium high in salts and glucose; tanned 130 days.	Original for worn soles	Strong	2.50	.26	1.79	16.56	11.94	28.50	1.73	4.11	24.89	44.56	55.86	.14	
		Heel seats of worn soles	do	2.60	1.75	1.67	15.67	12.70	28.37	1.72	4.36	24.19	44.02	54.95	.03	
		Balls of worn soles	do	4.36	2.84	1.45	15.09	14.24	29.33	1.56	4.43	22.93	43.45	52.77	— .72	84
25	Chestnut tannage, special; corresponding to lot 24 except no added salts and glucose and highly oiled.	Original for worn soles	do	.54	.25	7.48	14.54	6.50	21.04	.55	.33	25.67	45.56	56.34	— .22	
		Heel seats of worn soles	do	.91	.34	3.46	15.39	8.34	23.73	1.01	1.01	30.88	41.59	74.25	— .27	
		Balls of worn soles	do	4.00	1.77	2.79	16.07	11.77	27.84	1.57	1.88	23.18	44.42	52.18	—1.53	80
26	Chestnut tannage, regular; Colorado hides; bleached; quick tannage in motion; acid; medium low in salts and glucose; tanned 55 days.	Original for worn soles	None	1.33	.24	1.15	17.63	8.31	25.94	1.96	2.14	32.73	39.94	81.95	1.25	
		Heel seats of worn soles	do	1.66	.22	1.67	17.29	9.92	27.21	2.61	2.90	32.13	38.77	82.87	.82	
		Balls of worn soles	do	2.70	.74	1.98	14.55	9.42	23.97	2.15	2.61	34.68	38.63	89.77	.20	77
27	Hemlock tannage, regular; Texas hides; bleached; drummed; nonacid; high in salts and glucose; tanned 80 days.	Original for worn soles	do	1.48	.12	2.10	13.53	12.99	26.52	3.95	4.39	25.17	46.09	54.61	.31	
		Heel seats of worn soles	do	1.83	.20	2.52	12.60	13.96	26.56	4.27	4.95	25.52	45.20	56.46	.47	
		Balls of worn soles	do	3.06	1.00	2.39	12.96	13.17	26.13	3.18	4.12	25.93	44.55	58.20	— .05	81
28	Hemlock tannage, regular; dry Texas hides; bleached; drummed; nonacid; high in salts and glucose; tanned 104 days.	Original for worn soles	do	2.31	.13	4.40	15.93	14.98	30.91	6.31	4.38	25.97	38.59	67.30	.39	
		Heel seats of worn soles	do	2.14	.20	3.93	14.07	13.86	27.93	5.51	3.53	27.04	40.90	66.11	.75	
		Balls of worn soles	do	4.48	1.42	3.91	13.56	12.62	26.18	3.83	2.75	26.01	42.48	61.23	— .25	62

29	Hemlock tannage, regular; South American packer hides; bleached; drumned; dry dipped; nonacid; high in salts and glucose; tanned 120 days.	Original for worn soles	....do....	2.02	.18	2.33	14.51	14.95	29.46	4.54	6.54	28.08	39.95	70.29	1.13	
		Heel seats of worn soles	....do....	2.13	.27	3.04	13.38	13.89	27.27	4.11	5.91	29.39	40.03	73.42	1.09	
		Balls of worn soles	....do....	3.59	1.26	2.87	13.15	12.11	25.26	2.38	4.13	29.50	41.11	71.76	.22	72
30	Hemlock tannage, special; corresponding to lot 29 exeept unbleached and no added salts and glucose.	Original for worn soles	....do....	.36	.12	2.62	13.85	4.68	18.53	.27	.22	30.32	48.41	62.63	.20	
		Heel seats of worn soles	....do....	.80	.42	2.60	13.17	7.16	20.33	1.18	1.54	30.82	45.83	67.25	.20	
		Balls of worn soles	....do....	3.32	1.47	2.92	14.38	9.49	23.87	1.34	2.04	26.10	45.64	57.19	— .56	73
31	Hemlock tannage, regular; Texas hides; bleached; dry dipped; acid; high in salts and glucose; tanned 85 days.	Original for worn soles	Very slight	2.38	.29	2.39	15.60	15.45	31.05	4.42	6.49	26.81	39.45	67.96	1.78	
		Heel seats of worn soles	....do....	2.28	.40	2.72	15.48	14.93	30.41	4.01	6.21	27.27	39.20	69.57	1.65	
		Balls of worn soles	....do....	3.64	1.69	3.92	14.35	13.16	27.51	1.76	5.04	28.16	38.72	72.73	.31	30
32	Hemlock tannage, regular; Texas hides; bleached; dry dipped; acid; high in salts and glucose; tanned 94 days.	Original for worn soles	None	1.59	.39	2.20	14.47	13.87	28.34	4.15	4.82	30.21	38.86	77.74	.86	
		Heel seats of worn soles	....do....	1.79	.27	2.39	13.11	13.70	26.81	4.16	4.70	30.76	39.77	77.34	.99	
		Balls of worn soles	....do....	3.10	.88	2.22	12.12	12.84	24.96	2.70	4.00	32.49	39.45	82.36	.14	86
33	Hemlock tannage, special; corresponding to lot 32 except for low salts and glucose content.	Original for worn soles	....do....	1.19	.14	2.25	14.79	10.92	25.71	2.09	2.86	31.11	40.79	76.27	.97	
		Heel seats of worn soles	....do....	1.47	.19	1.67	14.39	11.70	26.09	2.43	3.33	31.35	40.70	77.03	.93	
		Balls of worn soles	....do....	3.67	1.39	2.39	12.67	11.95	24.62	1.92	3.15	31.86	39.74	80.17	— .03	73
34	Hemlock tannage, regular; dry B. A. hides; corresponding otherwise to lot 32.	Original for worn soles	....do....	1.55	.11	2.19	12.73	13.14	25.87	4.11	4.67	31.11	40.72	76.40	1.02	
		Heel seats of worn soles	....do....	1.81	.19	2.28	12.01	13.88	25.89	3.83	5.02	31.07	40.57	76.58	1.04	
		Balls of worn soles	....do....	2.85	1.00	3.01	11.50	12.57	24.07	2.47	4.40	31.54	40.38	78.11	.27	102
36	Oak belting tannage, regular; native steer hides; low in glucose and salts; medium high in grease and oil.	Original for worn soles	Strong	.23	.14	7.51	12.20	4.20	16.40	.00	.02	33.40	42.55	78.50	.41	
		Heel seats of worn soles	....do....	.64	.17	7.34	12.31	6.26	18.57	.91	1.11	32.38	41.54	77.95	.36	
		Balls of worn soles	....do....	3.00	1.57	7.10	12.03	7.85	19.88	.85	1.21	31.66	39.79	79.57	— .27	86
37	Oak belting tannage, regular; tanned by same company as lots 8 and 9; native steer hides; low in glucose and salts; medium high in grease.	Original for worn soles	....do....	.19	.15	6.62	10.98	3.61	14.59	.11	.02	30.40	48.24	63.02	.42	
		Heel seats of worn soles	....do....	.67	.20	5.75	10.74	6.09	16.83	1.09	1.30	29.77	47.45	62.74	.42	
		Balls of worn soles	....do....	3.71	1.64	6.03	11.47	8.67	20.14	1.28	1.67	26.80	45.39	59.04	— .39	82

[1] Also contained 1.73 per cent of barium chlorid.

TABLE 7.—*Composition of original and worn sole leathers*—Continued.

Lot No.	Description of leathers.	Sample.	Fluorescence.	Composition (moisture-free basis).												Average days wear per 9 irons.
				Total ash.	Insoluble ash.	Petroleum-ether extract.	Uncombined tannin.	Non-tannin.	Water solubles.	Epsom salts.	Glucose.	Combined tannin.	Hide Substance.	Degree of tannage.	Acidity P. & S.	
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	
38	Oak belting tannage, regular; tanned by same company as lots 1 and 2; native steer hides; low in glucose and salts; high in grease.	Original for worn soles..	Strong.....	0.23	0.09	15.21	11.96	4.74	16.70	0.07	0.13	26.97	41.03	65.73	0.14	
		Heel seats of worn soles..	.....do.....	.39	.14	10.73	12.74	5.22	17.96	.31	.24	28.23	42.94	65.74	.03	
		Balls of worn soles.....	.....do.....	2.76	1.65	6.54	14.55	7.45	22.00	.71	1.00	26.88	42.93	62.61	— .53	88
39	Chrome sole tannage, waxed, regular; Texas hides.	Original for worn soles..	.....	20.34	[1] 5.16	20.31	.....	.....	.....	.....	.....	.....	38.65	.....	.....	
		Heel seats of worn soles..	.....	20.39	[1] 5.23	19.73	.....	.....	.....	.....	.....	.....	39.73	.....	.....	
		Balls of worn soles.....	.....	23.04	[1] 5.12	16.71	.....	.....	.....	.....	.....	.....	41.94	.....	.....	96
40	Chrome sole tannage, waxed, regular; corresponding to lot 39 except from Maral bull hides.	Original for worn soles..	.....	21.85	[1] 5.01	19.72	.....	.....	.....	.....	.....	.....	37.97	.....	.....	
		Heel seats of worn soles..	.....	21.84	[1] 5.07	18.74	.....	.....	.....	.....	.....	.....	39.06	.....	.....	
		Balls of worn soles.....	.....	23.06	[1] 4.99	16.95	.....	.....	.....	.....	.....	.....	41.03	.....	.....	80
41	Chrome sole tannage, unwaxed, regular; domestic packer bulls.	Original for worn soles..	.....	11.46	[1] 4.20	.27	.....	.....	.....	.....	.....	.....	71.34	.....	.....	
		Heel seats of worn soles..	.....	11.13	[1] 4.09	.68	.....	.....	.....	.....	.....	.....	72.99	.....	.....	
		Balls of worn soles.....	.....	16.15	[1] 3.39	3.67	.....	.....	.....	.....	.....	.....	70.42	.....	.....	128
42	Chrome sole tannage, waxed, regular; corresponding to lot 41 except waxed.	Original for worn soles..	.....	7.96	[1] 2.70	35.47	.....	.....	.....	.....	.....	.....	47.52	.....	.....	
		Heel seats of worn soles..	.....	8.29	[1] 2.78	31.88	.....	.....	.....	.....	.....	.....	50.14	.....	.....	
		Balls of worn soles.....	.....	12.47	[1] 2.82	21.86	.....	.....	.....	.....	.....	.....	55.43	.....	.....	109
43	Chrome sole tannage, unwaxed, regular; domestic packer bull hides.	Original for worn soles..	.....	6.28	[1] 2.48	.74	.....	.....	.....	.....	.....	.....	89.08	.....	.....	
		Heel seats of worn soles..	.....	5.52	[1] 2.46	.55	.....	.....	.....	.....	.....	.....	88.55	.....	.....	
		Balls of worn soles.....	.....	10.73	[1] 1.85	2.19	.....	.....	.....	.....	.....	.....	81.70	.....	.....	124
44	Chrome sole tannage, waxed, regular; corresponding to lot 43 except waxed.	Original for worn soles..	.....	3.62	[1] 1.59	44.16	.....	.....	.....	.....	.....	.....	48.48	.....	.....	
		Heel seats of worn soles..	.....	3.76	[1] 1.87	39.70	.....	.....	.....	.....	.....	.....	54.63	.....	.....	
		Balls of worn soles.....	.....	11.05	[1] 1.98	21.64	.....	.....	.....	.....	.....	.....	59.82	.....	.....	118
45	Chrome sole tannage, waxed, regular; corresponding to lot 44 except from dry China buffalo or Java hides.	Original for worn soles..	.....	6.68	[1] 1.83	33.74	.....	.....	.....	.....	.....	.....	57.07	.....	.....	
		Heel seats of worn soles..	.....	6.53	[1] 1.89	32.55	.....	.....	.....	.....	.....	.....	59.32	.....	.....	
		Balls of worn soles.....	.....	11.01	[1] 1.64	20.73	.....	.....	.....	.....	.....	.....	61.23	.....	.....	99

[1] Total chromic oxid.

Total and Insoluble Ash.

The total ash content of the balls of the worn soles is decidedly higher than that of the original leather; that of the heel seats is but slightly greater.

The soluble ash content of the heel seats of the vegetable-tanned leathers, with the exception of the lot containing barium chlorid, increased on an average 0.26 per cent and the insoluble ash content increased 0.07 per cent, making the gain for total ash equivalent to 0.33 per cent. Both the soluble and insoluble ash contents are decidedly higher in the balls of the worn soles, being 1.11 and 1.19 per cent, making the increase for the total ash equivalent to 2.3 per cent. Only four lots show a loss in total ash for the heel seats, and this loss is very slight, the greatest being 0.17 per cent. The balls of the worn soles in no case show a loss in total ash.

Three of the seven lots of chrome-tanned leathers show a slight increase in the total ash of the heel seats, and four show a slight decrease, making the average a loss of 0.1 per cent. The balls of the worn soles of all chrome-tanned lots show an average gain in total ash of 4.19 per cent, despite the comparatively high ash content of the original leathers.

Chromium Oxid.

The chromium oxid content of the chrome-tanned leather remains practically constant, showing a tendency to only a slight decrease in the worn soles.

Petroleum-Ether Extract.

The petroleum-ether extract results are not as consistent as the ash results. The grease content of the heel seats and balls of the worn soles, however, shows a general tendency to increase. There are indications that the grease content of the worn leather reaches an equilibrium which may differ for each leather or kind of leather.

The petroleum-ether extract in sole leathers containing 4 per cent or more shows a consistent tendency to decrease on wearing. This is particularly noticeable in the case of lot 25 which was highly oiled, the losses for this lot being 4.02 per cent for heel seats and 4.69 per cent for balls. Nine of the vegetable-tanned sole leather lots show loss of grease from the heels seats, and six show a loss from the balls of the worn soles. The average increase in the petroleum-ether extract of the 34 lots of sole leather is 0.39 per cent for the heel seats and 0.53 per cent for the balls. Omitting lot 25, these results become 0.53 and 0.69 per cent.

As compared with the sole leathers, the belting leathers are high in petroleum-ether extract, and all three lots show a loss in both heel seats and balls, the average being 1.84 and 3.22 per cent, respectively. In two lots the loss is slight, and it would seem that it is not entirely in proportion to the original oil content.

All the waxed chrome-tanned sole leathers show losses in petroleum-ether extract, the average being 2.16 per cent for the heel seats and 11.10 per cent for the balls. The losses for the heel seats vary from 0.58 to 4.46 per cent and those for the balls from 2.77 to 22.52 per cent.

The unwaxed chrome-tanned sole leathers show an increase in the balls of 3.40 and 1.45 per cent, and for one lot an increase of 0.41 per

cent for the heel seats and for the other a loss of 0.19 per cent. The cause of these increases is unexplained.

Epsom Salts.

The epsom salts content is calculated from the total magnesium present in dilute-hydrochloric-acid-soluble form in the ash of the leather and is not limited to the quantity that may have been present as magnesium sulphate.

The epsom salts content of all lots of vegetable-tanned sole leather shows an average increase in the worn soles of 0.21 per cent for the heel seats and an average decrease of 0.34 per cent for the balls of worn soles. The heel seats of 11 lots and the balls of 19 lots show a loss of epsom salts. The change in epsom salts content corresponds somewhat to the epsom salts content of the original leather, as is shown by the results in Table 8.

Table 8.—*Change in epsom salts content after wear.*

Original epsom salts content.	Number of lots.	Number of lots showing loss in—	
		Heel seats.	Balls.
Between—			
0 and 2 per cent	16	1	2
2 and 3 per cent	5	2	4
3 and 4 per cent	7	3	7
4 per cent and over	6	5	6

The epsom salts content of the soles cut from the belting leathers is interesting in that these leathers were originally almost entirely free from magnesium. The increase during wear in magnesium, calculated as epsom salts, is nearly 1 per cent on the average. Considering that the soil in the section where the experiments were conducted is "alkali soil," this increase in magnesium is readily explained.

Glucose.

While an increase in the magnesium content of worn soles might be expected under certain conditions of wear, a similar increase in the glucose content could hardly be expected. Yet of 34 lots of vegetable-tanned sole leather, 23 show a gain in glucose in the heel seats and 20 show a gain in the balls of the worn soles. The increase in the heel seats ranges from 0.12 to 1.32 per cent and in the balls from 0.03 to 1.82 per cent. The average shows for the heel seats a gain of 0.32 per cent and for the balls a loss of 0.05 per cent.

To guard against unduly high glucose results, due to the influence of magnesium and possibly other salts, many of the glucose determinations were checked by Low's volumetric method for determining the copper in the reduced cuprous oxid. The difference between the glucose results obtained by the two methods was not sufficient to account for the gain in glucose through contamination of the cuprous oxid.

TABLE 9.—*Change in glucose content after wear.*

Original glucose content.	Number of lots.	Number of lots showing loss in—	
		Heel seats.	Balls.
Less than 4 per cent	17	.....	.....
More than 4 per cent	17	11	15

Here again the results obtained for the belting leathers are very interesting, since the leathers mentioned in Table 9 originally contained only traces of glucose. The average gain in glucose for the heel seats is 0.83 per cent and for the balls 1.24 per cent.

These results suggest a change in the leather or in some of its component parts with age. The most plausible explanation would seem to be a slow hydrolysis of the tannin and related nontannin materials, promoted possibly by the alkaline condition of the soils in the sections of the country where the shoes were worn.

WATER SOLUBLES.

As is to be expected from the review of the epsom salts and glucose results, the water-soluble materials show a general tendency to increase in the heel seats and balls of the worn soles (Table 10).

TABLE 10.—*Change in water solubles content after wear.*

Original water solubles content.	Number of lots.	Number of lots showing gain in—	
		Heel seats.	Balls.
Less than 20 per cent	3	3	3
Between 20 and 25 per cent	8	7	7
Between 25 and 30 per cent	17	7	5
More than 30 per cent	6	2	.....

The three lots of belting leathers which originally contained less than 20 per cent of water-soluble material show an increase, averaging 1.89 per cent for the heel seats and 4.78 per cent for the balls of the worn soles. It seems reasonable to conclude that the increase in water-soluble materials was due to the absorption by the soles of salts from the dry alkali soil where the shoes were worn.

UNCOMBINED TANNIN.

The uncombined tannin varies but little between the original and worn leathers, the differences being almost always within the limits of analytical error. There is, however, a consistent tendency for the uncombined tannin content of both the heel seats and balls to be slightly lower than that in the original leathers.

Nontannins.

As would be expected from the increase in glucose and epsom salts, the nontannins show a tendency to be greater in the worn parts of the leathers, except in those cases where the original leathers contain high percentages of nontannins.

Hide Substance and Combined Tannin.

The results from the hide substance and combined tannin determinations also show a general tendency to be lower in both the heel seats and balls of the worn soles than in the unworn leather. This would follow from the absorption of soluble materials by the soles.

Acidity.

Without exception the acidity is lower in the balls of the worn soles than in the unworn leather, and in all but 8 out of 37 lots the results indicate that the leather was alkaline in reaction after wear. This is undoubtedly due to the nature of the soil in the region where the shoes were worn.

SUMMARY.

The experiments reported in this bulletin were conducted in a region having a very dry climate and "alkali" soil. Results obtained under such conditions may not and in some cases probably will not hold for leather worn in humid climates. Army types of leather and shoes, worn under Army service conditions, were used for the tests, so that the comparisons and conclusions here indicated may not apply to the ordinary kinds of leather and shoes subjected to civilian wear. Although the results of these experiments can not be considered final, they are significant indications which, because of the large number of samples involved, may be accepted until additional data are obtained. Wear experiments, while offering the best opportunity to obtain valuable information, also present many difficulties, so that final conclusions from a single series of tests are seldom justifiable.

Upper leathers.—From the standpoint of durability, all types of upper leather were satisfactory when the short life of sole leather is considered. None of them showed signs of being nearly worn out at the close of the experiments. Retanned chrome leather was the best in pliability and softness, that with the grain finish being slightly better than that with the flesh finish. Bark-tanned upper leather was the least satisfactory in appearance and pliability, 58 per cent of the uppers made from this leather being rated as too stiff and hard.

Soling materials.—Fiber soles of the kinds used were not suitable for the conditions of wear, owing principally to the fact that as soon as the soles had worn down through the stitches they frequently ripped or broke off. Imperfections, such as ripping, bulging, chipping, and breaking, were numerous in the fiber soles. When these failures did not develop, however, the fiber soles wore well, being rated second in wear. Such imperfections were negligible in the leather soles.

Types of shoes.—That certain features in the construction of the shoes played an important part in their serviceability is strongly indicated by the excessive toe wear frequently found during this in-

vestigation. Disregarding the possibility of misfitting, it would seem that a full double sole and double shank of heavy leather are responsible for the wasteful excessive toe wear. A shoe with such a sole bends but little and the weight of the body is concentrated at the extreme end of the sole, instead of being distributed over a greater area at the ball. Even when a double sole is used on the ball of the foot, the shank should not be doubled, thus saving leather in making the shoe, lengthening its period of service, and reducing the cost of repair.

Serviceability of various tannages.—The average wear resistance of the vegetable-tanned sole leathers, classified according to the predominating tanning material, is practically the same for all three types, being per 9 irons as follows: Oak bark tannages, 78 days; hemlock bark tannages, 79 days; and chestnut wood extract tannages, 80 days. Belting leather shows a slightly higher wear resistance, the average wear per 9 irons being 85.5 days. Waxed chrome-tanned leather, with 102 days wear, was next in order, while unwaxed chrome-tanned leather, with an average of 126 days wear, was best of all. Fiber soles, with an average of 122 days wear, were a good second, except for the physical failures already discussed. The results are charted in Figure 2.

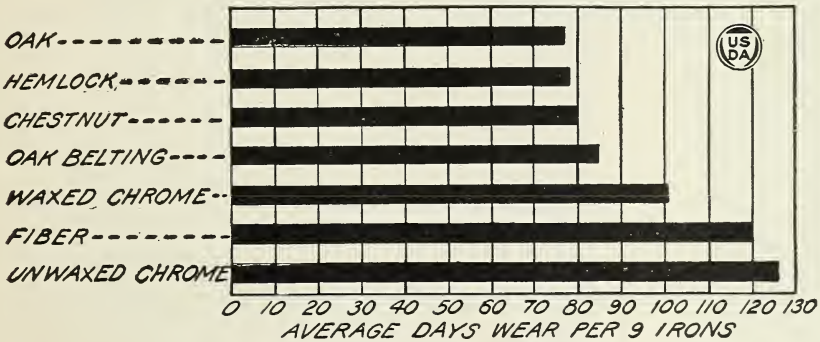

FIG. 2.—Summary of wear data on soles.

The longer wear of the chrome-tanned leathers, both unwaxed and waxed, and of the fiber soles warrants further consideration of these materials. The results indicate that unwaxed chrome-tanned leather may be exceptionally serviceable in dry sections of the country. The influence of the climate in this connection must be emphasized. Unwaxed chrome-tanned leather is not suited for wear in damp or wet places, because it is very porous and consequently readily takes up water. This is the primary reason for the manufacture of waxed chrome-tanned leather, which is simply chrome-tanned leather impregnated with large quantities of waxes and other materials to make the leather more water resistant.

Loaded leathers.—Under the conditions of these tests, loading with glucose and epsom salts does not materially affect the serviceability of leather. It simply adds to the cost. These findings, however, might have been quite different had the shoes been worn where the climate was wet.

Rolled leathers.—Approximately 16 per cent greater wear for the rolled than for the unrolled leathers was shown.

Well-oiled leathers.—The results on leather oiled in various ways are not satisfactory, because the differences in oil contents of the lots were not sufficiently great. The indications are that the sole leathers of normal oil contents wear about 8 per cent longer than do the well-oiled leathers. This indication needs further confirmation before it can be accepted as final.

Acid tannage.—Leather from the acid tannages did not wear quite as long as that from the nonacid tannages. For several reasons, however, this is not regarded as conclusive.

Section of the bend.—The average wear per 9 irons for soles from the shoulder end of the bend was 79 days, as against 85 days for those from the butt end. These indications are in harmony with practical experience and with other experiments on leathers from the different sections of the hide.

The outstanding indications from this investigation, which was conducted under very dry conditions, are: (1) The superior pliability of retanned chrome and chrome-tanned upper leathers; (2) the objectionable features of fiber soles and the long wear of those that did not develop such features; (3) the longer wear, thickness for thickness, of rolled vegetable-tanned sole leather as compared with that of the corresponding unrolled leathers; and (4) the strikingly longer wear of chrome-tanned sole leathers, especially of the unwaxed chrome-tanned leather.

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